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Characterization of chemical reaction on heat transfer through the nano fluid

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Abstract

The chemical reaction of metal particle with the solvent is natural and decomposition of the metal particle is a natural phenomenon. But, this decomposition affects the viscosity and the fluid flow. The inclusion of chemical reaction rate parameter in the expression of viscosity given by Graham A.L (Applied Science Research, 37(3), pp.275-286(1981)) address the behavior of the viscosity of the Nano fluid in its flow and heat transfer. The heat transfer is more for large volume fraction of the solid. The heat transfer is less due to the decomposition of metal particle

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Keywords: Cu-H $_2$O; Nano - Fluid; Viscosity; Vertical Plate; Heat Transfer; FEM.

Nomenclature

B_0	Constant applied magnetic field (Wb m^{-2})
c_p	Specific heat at constant pressure (J kg^{-1} K^{-1})
g	Gravity acceleration (m s^{-2})
J	Current density
M	Dimensionless magnetic field parameter
n	Dimensionless frequency
Nu	Local Nusselt number

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Pr Prandtl number
Q Dimensional heat source (kJ s^{-1})
Q_H Dimensionless heat source parameter (kJ s^{-1})
S Dimensionless suction parameter
t Dimensionless time (s)
T Local temperature of the Nano-fluid (K)
T_w Wall temperature (K)
T_∞ Temperature of the ambient Nano-fluid (K)
u, w Dimensionless velocity components (m s^{-1})
U_0 Characteristic velocity (m s^{-1})
k Thermal conductivity
R_a Radiation parameter

Greek symbols:
α Thermal diffusivity (m^2 s^{-1})
β_T Thermal expansion coefficient (K^{-1})
ε Dimensionless small quantity ($<<1$)
ϕ Solid volume fraction of the Nano-particles
μ Dynamic viscosity (Pa s)
ψ Kinematic viscosity (m^2 s^{-1})
θ Dimensionless temperature
σ Electrical conductivity (m^2 s^{-1})
σ_1 Stefan-Boltzmann constant
δ Mean absorption Coefficient
γ Inclination angle of the plate
ρ Density

Superscript:
– Dimensional quantities

Subscripts:
f Fluid
s Solid
nf Nano-Fluid

1. INTRODUCTION:

The study of convective Nano fluid heat transfer dominated the heat transfer through fluids, due to strong physical properties of the mater (solid + base fluid). Literature survey proved that the study of Nano fluid heat transfer was worth enough to implement in industries. Sarit Kumar Das and Xiang- Qi Wang stressed the lack of heat transfer mechanisms through Nano fluids and the interaction of metal particle with solvent. However, at later stages many authors attempted to study the thermal conductivity, viscosity and physical parameters. Tiwari Arun Kumar studied the thermal conductivity and viscosity of Nano fluids with various models and concluded that existing literature was still unclear to match the experimental and theoretical results.

Recently Gbadeyan, J.A reports that the increase in Brownian motion reduced the heat transfer rate. M.A.A.Hamad concluded that the Nano particle inclusion in the base fluid changes the flow pattern significantly. To match the experimental and theoretical results Hassan A.M. and GVPN Srikanth are attempted by including the chemical reaction coefficients in the diffusion equation.

In the view of above literature survey, we want to investigate the heat transfer through Nano fluid (cu-water) with a focus on decomposition of the Nano particle (cu) in water, due to the chemical reaction by considering the viscosity proposed by Graham A.L and thermal conductivity proposed by Jang and Choi.

2. MATHEMATICAL FORMULATION:

The unsteady three dimensional free convection flow of a Nano-fluid past a inclined permeable, semi-infinite oscillating flat plate in the presence of an applied magnetic field with constant heat source and radiation is considered. As per cartesian coordinate system $(\bar{x},\bar{y},\bar{z})$, the flow is assumed to be in the $\bar{x}$ direction, which is taken along the plate, and $\bar{z}$ - axis is normal to the plate. We assume that the plate has an oscillatory movement on time $\bar{t}$ and frequency $\bar{n}$ with the velocity u(0,t), which is given as $u(0,t) = U_0\left[1+\varepsilon\cos(nt)\right]$ where ε is a small constant parameter ($\varepsilon << 1$) and U_0 is the characteristic velocity. We consider that initially (t < 0) the fluid and the plate are at rest. A uniform external magnetic field B_0 is taken to be acting along the $\bar{z}$ -axis. Also assume that the induced magnetic field is small compared to the external magnetic field B_0. The surface temperature is assumed to have the constant value T_w while the ambient temperature has the constant value T_∞, where $T_w > T_\infty$. The conservation equation of current density $\nabla . J = 0$ gives J = constant. Since the plate is electrically non-conducting, this constant is zero. It is assumed that the plate is infinite in extent and hence all physical quantities do not depend on $\bar{x}$ and $\bar{y}$ but depend only on $\bar{z}$ and $\bar{t}$,

i.e, $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

It is further assumed that the regular fluid and the suspended Nano-particles are in thermal equilibrium and no slip occurs between them. Under Bossinesq and boundary layer approximations, the boundary layer equations governing the flow and temperature are:

$$\frac{\partial w}{\partial z} = 0 \tag{1}$$

$$\frac{\partial u}{\partial t} + w\frac{\partial u}{\partial z} = \frac{1}{\rho_{nf}}\left[\mu_{nf}\frac{\partial^2 u}{\partial z^2} + (\rho\beta_T)_{nf}\, g\,(T - T_\infty)\, \mathrm{Cos}\,\gamma - \sigma B_0^2 u\right] \tag{2}$$

$$\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial z} = \alpha_{nf}\frac{\partial^2 T}{\partial z^2} - \frac{Q}{(\rho c_p)_{nf}}(T - T_\infty) - \frac{1}{(\rho c_p)_{nf}}\frac{\partial q_r}{\partial z} \tag{3}$$

The appropriate initial and boundary conditions for the problem are given by

$$
\begin{aligned}
&u(z,t) = 0,\ T = T_\infty \quad \text{for } t < 0\ \forall z \\
&\left.\begin{aligned}
&u(0,t) = U_0\left[1+\frac{\varepsilon}{2}(e^{int}+e^{-int})\right], T(0,t) = T_w \\
&u(\infty,t)\to 0, T(\infty,t)\to T_\infty,\ \ \varepsilon << 1
\end{aligned}\right\}\ t \ge 0
\end{aligned} \tag{4}
$$

Thermo-Physical properties are related as follows:

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_s,\ \alpha_{nf} = \frac{k_{nf}}{(\rho c_p)_{nf}}$$

$$(\rho c_p)_{nf} = (1-\phi)(\rho c_p)_f + \phi(\rho c_p)_s$$

$$(\rho\beta)_{nf} = (1-\phi)(\rho\beta)_f + \phi(\rho\beta)_s$$

$$\frac{\mu_{nf}}{\mu_f} = 1 + 2.5\,\phi + 4.5\left[\frac{1}{\dfrac{h}{d_p}\left(2+\dfrac{h}{d_p}\right)\left(1+\dfrac{h}{d_p}\right)^2}\right]$$

$$k_{nf} = k_f(1-\phi) + \beta_1 k_p \phi + c_1 \frac{d_f}{d_p} k_p \mathrm{Re}^2 d_p\, pr\, \phi$$

Due to chemical Reaction by the solvent and the metal particle the rate of change of the size of the particle can be considered as:

$$\frac{dd_p}{dt} = -K\,d_p$$

$$\Rightarrow\ d_p = d_0\, e^{-Kt}$$

Where d_p the diameter of the metal particle, d_0 is the initial size of the particle (assumed as 50 nm) and K is the reaction rate:

$$\frac{\mu_{nf}}{\mu_f} = 1 + 2.5\,\phi + 4.5\left[\frac{1}{\left(\frac{h\,e^{Kt}}{50}\right)\left(2+\frac{h\,e^{Kt}}{50}\right)\left(1+\frac{h\,e^{Kt}}{50}\right)^2}\right]$$

$$k_{nf} = k_f(1-\phi) + \beta_1 k_p \phi + \frac{c_1}{50}\, d_f\, e^{\kappa t}\, k_p\, Re^2\, d_p\, pr\,\phi \qquad (5)$$

where $\beta_1 = 0.01$ is a constant for considering the kapitza resistance per unit area

$c_1 = 18 \times 10^6$ is a proportionality constant

$$Re\, d_p = \frac{d_p}{\nu_f}\frac{\kappa T}{3\pi \mu_f d_p l_f} = \frac{1.381\times 10^{23}\,T}{\nu_f 3\pi \mu_f (0.738)}$$

$d_f = 0.384$ nm for water

$$Pr = \text{Prandtl number} = \frac{\nu_f}{\alpha_f}$$

l_f = Mean free path = 0.738

κ = Boltzmann constant , $T = 300k$

The thermo-physical properties (values) of the materials used are as follows:

Table

Physical Properties	Water	Copper(Cu)
$C_p\ (J/kg\ K)$	4,179	385
$\rho\ (kg/m^3)$	997.1	8,933
$\kappa\ (W/m\ K)$	0.613	400
$\beta_T \times 10^{-5}\ (1/K)$	21	1.67
μ	8.94×10^{-4}	-----

We consider the solution of Esq. (1) as $w = -w_0$ (6)

Where the constant w_0 represents the normal velocity at the plate which is positive for suction ($w_0>0$).Thus, we introduce the following dimensionless variables:

$$z = \left(\frac{\nu_f}{U_0}\right)Z,\quad t = \left(\frac{\nu_f}{U_0^2}\right)\tau,\quad n = \left(\frac{U_0^2}{\nu_f}\right)\eta,\quad u = UU_0,\quad \theta = \frac{T - T_\infty}{T_w - T_\infty},\quad q_r = -\frac{4\sigma_1}{3\delta}\frac{\partial T^4}{\partial y}$$

We assume that the temperature differences within the flow are sufficiently small so that the T^4 can be expressed as a linear function after using Taylor series to expand T^4 about the free stream temperature T_∞ and neglecting higher-order terms. This result is the following approximation:

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4$$

By using above, we obtain

$$\frac{\partial q_r}{\partial z} = -\frac{16\sigma_1}{3\delta}\frac{\partial^2 T^4 T_\infty^3}{\partial z^2} \qquad (7)$$

Using equations 4,5,6,7 the Equations 2 and 3 can be written in the following dimensionless form:

$$\left[1-\phi+\phi\left(\frac{\rho_s}{\rho_f}\right)\right]\left(\frac{\partial U}{\partial \tau}-S\frac{\partial U}{\partial Z}\right) = 1+2.5\,\phi+4.5\left[\frac{1}{\left(\frac{h\,e^{Kt}}{50}\right)\left(2+\frac{h\,e^{Kt}}{50}\right)\left(1+\frac{h\,e^{Kt}}{50}\right)^2}\right]\frac{\partial^2 U}{\partial Z^2}$$
$$+\left[1-\phi+\phi\frac{(\rho\beta_T)_s}{(\rho\beta_T)_f}\right] Gr\,\theta\,\cos\gamma - MU$$

$$\left[1-\phi+\phi\frac{(\rho c_p)_s}{(\rho c_p)_f}\right]\left(\frac{\partial\theta}{\partial\tau}-S\frac{\partial\theta}{\partial Z}\right)=\frac{1}{Pr}\left(1-\phi+0.01\phi\frac{k_p}{k_f}+\frac{k_p}{k_f^{\,2}}\,\phi\,\frac{\rho_f^{\,2}\,c_{pf}\,e^{Kt}}{50\,\mu_f^{\,3}}28632.9991\times10^{-52}\right)\frac{\partial^2\theta}{\partial Z^2}$$
$$-\frac{1}{Pr}Q_H\theta+\frac{1}{Pr}\frac{4}{3}\frac{1}{Ra}\frac{\partial^2\theta}{\partial Z^2}$$

Where the corresponding boundary conditions (4) can be written in the dimensionless form as:

$$\left.\begin{aligned} &U(z,t)=0,\ \theta(z,t)=0 \quad \text{for } t<0\ \forall\ z\\ &U(0,t)=U_0\left[1+\frac{\varepsilon}{2}(e^{int}+e^{-int})\right],\ \theta(0,t)=1\\ &U(\infty,t)\to 0,\ \theta(\infty,t)\to 0\end{aligned}\right\}\forall\ t\ge 0$$

Here Pr is the Prandtl number, S is the suction (S > 0) parameter, M is the magnetic parameter, Ra is the Radiation parameter and Q_H is the heat source parameter, Gr is the Grashof number, which are defined as:

$$Pr=\frac{\nu_f}{\alpha_f},\ S=\frac{w_0}{U_0},\ M=\frac{\sigma B_0^2\nu_f}{\rho_f U_0^2},\ Ra=\frac{4\alpha\sigma_1 T_\infty^3}{\delta k_{nf}},\ Q_H=\frac{Q\nu_f^2}{k_f U_0^2},\ Gr=g\beta_{Tf}\left(T_w-T_\infty\right)\nu_f$$

Where the velocity characteristic U_0 is defined as:

$$U_0=\left[g\beta_f(T_w-T_\infty)\nu_f\right]^{1/3}$$

The local Nusselt number (Nu) in dimensionless form:

$$\mathrm{Nu} = -\frac{k_{nf}}{k_f}\theta'(0)$$

3. SOLUTION OF THE PROBLEM:

The governing equations are solved by using Galerkin Finite Element Method (FEM) as given in J. N. Reddy. The one dimensional study along the plate with three nodded elements are considered and the entire domain is divided into 100 elements, for computational purpose the infinite plate is limited to 6 units. We have chosen Pr = 6.2, nt = $\pi/2$, n = 10, ε = 0.02.

4. RESULTS:

The momentum decreases with increase in volume fraction (ϕ) from Fig.1 (a). The 5% of solid volume fraction significantly decreases the momentum when compared with usual fluid. From Fig. 1(b) the suction (S) affects the momentum.

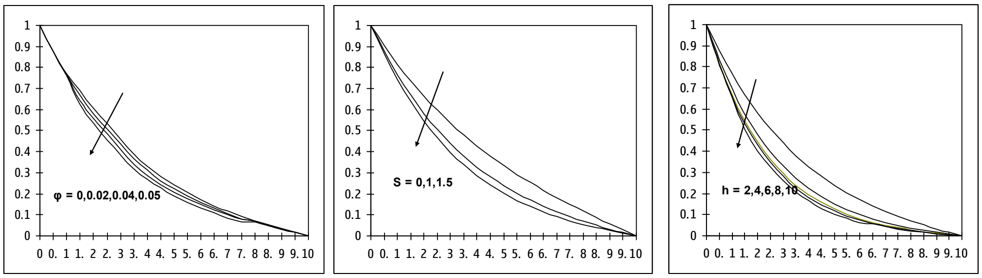

Fig. 1 (a) Variation of U with ϕ (b) Variation of U with S (c) Variation of U with h

As the suction increases, the momentum decreases more rapidly compare with no suction. The increase in h drastically drops the momentum from Fig. 1(c). This occurs due to the adhesion of the layer around the Nano-particle or more packing fraction of the particles. From Fig. 2(a) the increase in thermal buoyancy the momentum increases unlike the other profiles of the momentum.

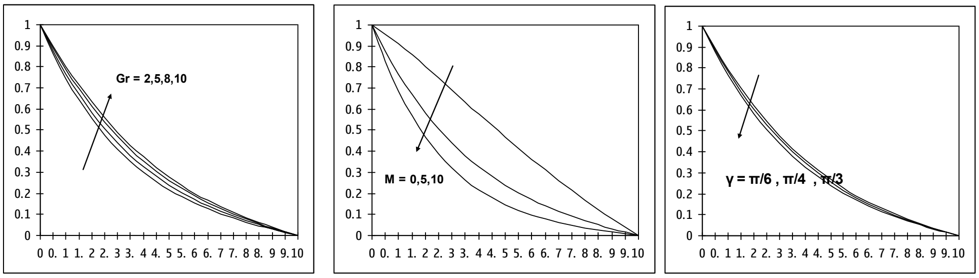

Fig. 2 (a) Variation of U with Gr (b) Variation of U with M (c) Variation of U with γ

From Fig. 2(b) the magnetic field (M) affects the momentum very much. The momentum is almost linear in the absence of the magnetic field and decreases with increase in M. From Fig.2(c) the momentum decreases slightly with increase in inclination angle (γ).

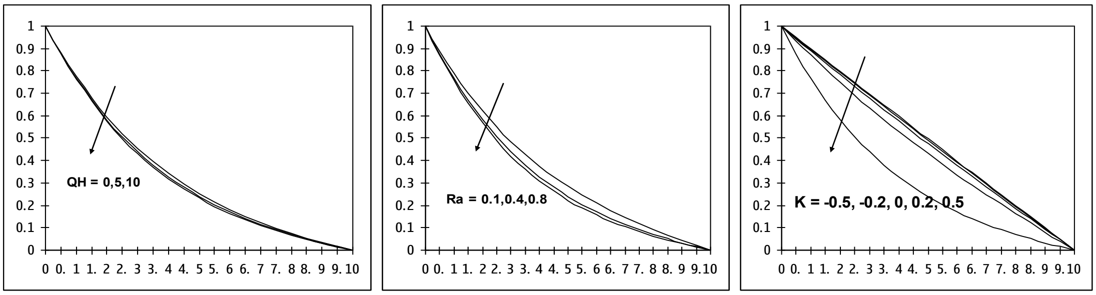

Fig. 3 (a) Variation of U with Q_H (b) Variation of U with Ra (c) Variation of U with K

From Fig. 3(a) the heat source (Q_H) has not having much impact on momentum. But, the momentum decreases with increase in heat source. From Fig. 3(b) the radiation decreases the momentum with increase in Radiation (Ra). It is also found that there is no impact on momentum for Ra > 0.4. From Fig. 3(c) the momentum variation is observed for generative (K < 0) and destructive (K > 0) chemical reactions. The generative chemical reaction produces almost the uniform momentum whereas; the destructive chemical reaction tends to exponential decay in the momentum along the plate.

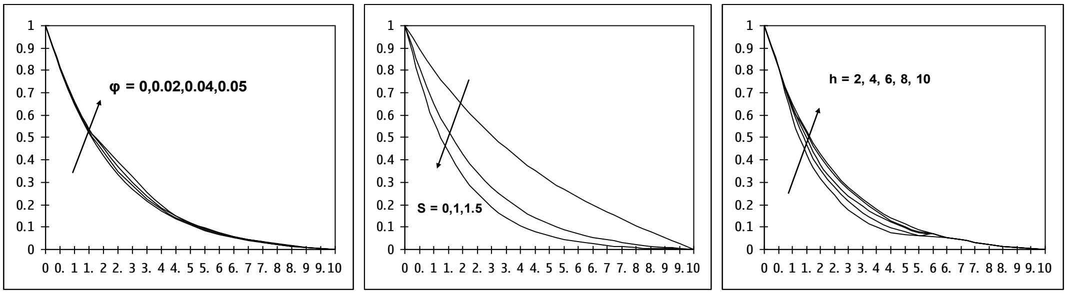

Fig. 4(a) Variation of θ with ϕ (b) Variation of θ with S (c) Variation of θ with h

The temperature rises with increase in the solid volume fraction (ϕ) from Fig. 4(a). From Fig. 4(b) interestingly the suction (S) reduces the temperature along the plate almost exponentially. From Fig. 4(c) the layer (h) acts as a semimetal to enhance the temperature along the plate.

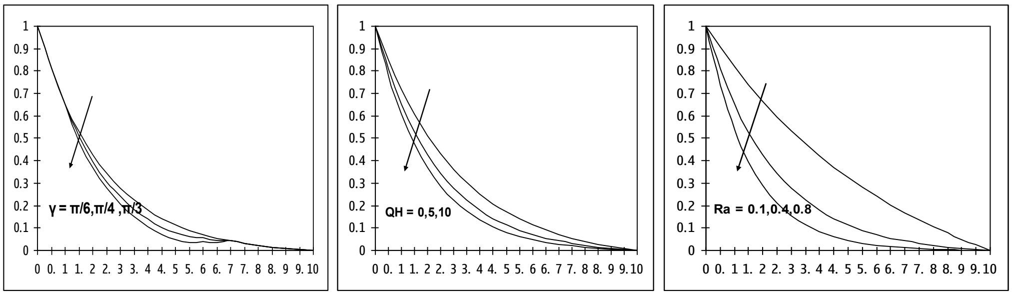

Fig. 5(a) Variation of θ with γ (b) Variation of θ with Q_H (c) Variation of θ with Ra

From Fig. 5(a) the inclination angle (γ) of the plate reduces the temperature. The thermal boundary layer has thinned by layer around the nano- particle and the inclination of the plate. From Fig. 5(b) the heat source (Q_H) decreases the temperature. From Fig. 5(c) the radiation drastically drops the temperature even for slightly higher values (Ra > 0.1). From Fig. 6(a) the generative chemical reaction (K) has no impact on temperature whereas, the destructive chemical reaction reduces the temperature slightly.

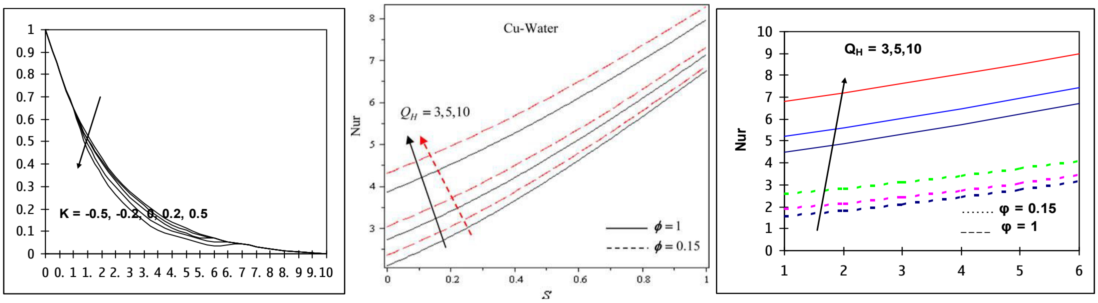

Fig. 6 (a) Variation of θ with K (b) Variation of Nusselt Number **(**M.A.A.Hamad**)** (c) Variation of Nusselt Number

Fig. 6(b) depicts the variation of heat transfer by M. A. A. Hamad and I.Pop. Fig. 6(c) depicts the variation of heat transfer in the present study for K = 0.5 at the base of the plate. As the suction and heat source increases the heat transfer rate increases for ϕ = 0.15, 1. However, the heat transfer rate has no much variation for different S. The heat transfer is more for large volume fraction of the solid. The heat transfer is less when compared with above authors due to the decomposition of metal particle.

5. Conclusion:

- The destructive chemical reaction exponentially decreases the velocity due to adhesion of the liquid layer around the metal particle.
- Both types of chemical reactions (destructive and generative) reduce the temperature along the plate and the variation is very narrow.

References

Gbadeyan,J.A., Olanrewaju, M.A. and Olanrewaju,P.O.,Boundary Layer Flow of a Nano fluid past a Stretching Sheet with a Convective Boundary Conduction in the Presence of Magnetic Field and Thermal Radiation(2011) Australian Journal of Basic and Applied Sciences,5(9):1323-1334.

Graham A.L., On the viscosity of suspension of solid spheres (1981), Appl.Sci.Res, 37(3),27

G.V.P.N.Srikanth, B.Suresh Babu, Dr.G.Srinivas, Heat and Mass Transfer of a MHD Nano Fluid with Chemical Reaction Effects (2014), International Journal of Mechanical And Production Engineering, ISSN: 2320-2092, Volume- 2, Issue- 3, March-2014.

Hassan A.M. El - Arabawy, Exact Solutions of Mass Transfer over a Stretching Surface with Chemical Reaction and Suction/ Injection (2009), Journal of Mathematics and Statistics 5 (3): 159- 166, ISSN: 1549-3644.

J. N. Reddy and D. K. Gartling, the Finite Element Method in Heat Transfer and Fluid Dynamics, Ed.3, CRC Press, Taylor & Francis Group, Boca Raton, 2010.

M.A.A. Hamad and I.Pop, Unsteady MHD free convection flow past a vertical permeable flat plate in a rotating frame of reference with constant heat source in a nano fluid, Heat Mass Transfer (2011), 47:1517-1524.

Sarit Kumar Das, Stephen U.S. Choi, Hrishikesh E.Patel, Heat Transfer in Nano Fluids – A Review, Heat Transfer Engineering (2006), 27(10):3-19.

Tiwari Arun Kumar, Ghosh Pradyumna and Sarkar Jahar, Investigation of Thermal Conductivity and Viscosity of Nano Fluids, Journal of Environmental Research and Development, Vol.7 No.2, 2012.

Xiang – Qi Wang, Arun S.Mujumdar, Heat Transfer Characteristics of Nano Fluids: A Review, International Journal of Thermal Sciences 46 (2007) 1-19.